Study and portfolio review of the projects on industrial symbiosis in DG Research and Innovation: Findings and recommendations
Study and portfolio review of the cluster of projects on industrial symbiosis in the Directorate for Prosperity in DG Research and Innovation: Findings and recommendations

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Study and portfolio review of the projects on industrial symbiosis in DG Research and Innovation: Findings and recommendations industrial symbiosis

Klaus H. Sommer
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EXECUTIVE SUMMARY

In an effort to establish portfolio management for European Commission-funded projects we analysed a cluster of 28 industrial symbiosis projects, involving 14 different industrial sectors and two established industrial symbiosis sites. In order to foster Europe’s development towards CO₂ neutrality and a circular economy in industry we recommend that research and innovation (R&I) investments and European Commission funding for industrial symbiosis be further strengthened. We firmly believe that understanding of the underlying processes to establish and maintain industrial symbiosis (i.e. how to start/facilitate industrial symbiosis interaction/cooperation, which barriers need to be overcome, how to identify the potential for interaction and sharing of mutual benefits) is needed to secure and accelerate its implementation and deployment. We therefore propose to use the concept of ‘symbiosis readiness level’ (SRL) to identify and define the level of maturity of symbiotic interactions and drive the progress of industrial symbiosis projects and initiatives. In our analysis, facilitation is seen as one of the most important elements to foster the establishment of industrial symbiosis. In this context, it is recommended to develop an appropriate facilitation framework and involve suitable actors (e.g. the industrial park owner/manager, the municipality or the chamber of commerce and/or the association of a cluster of companies) as potential facilitators.

We also recommend the establishment of a community of practice for industrial symbiosis, which could be an entity with a mandate to provide guidelines for industrial symbiosis (e.g. identify best practices and maintain an up-to-date inventory of industrial symbiosis projects and of opportunities for cross-sectoral cooperation), promote its benefits and help in educating and establishing industrial symbiosis. This community could publish a handbook on how to establish industrial symbiosis, which would help promote its acceptance and adoption in an accelerated way. Establishing a data and information exchange platform will also be fundamental as opportunities can be more easily identified if a reliable and open data source is available for those interested in implementing industrial symbiosis.

Modern digital tools like digital twins for process modelling and control, blockchain and artificial intelligence for confidential data management should be considered.

In Section 3.3 we have identified focus areas for R&I investment from the public and/or the private side for methods and tools and technologies. We believe that pilot and testing facilities are needed to demonstrate viability of technologies and installations before decision-makers will be convinced to make larger investments.

Furthermore, it is recommended to establish hubs for circularity, as proposed by the SPIRE public–private partnership (PPP), as a vehicle to promote industrial symbiosis and showcase its potential environmental, social and economic advantages. This would be a good approach to address the need for a large-scale first-of-a-kind demonstration of industrial symbiosis technologies and concepts.

In terms of capacity building, industrial symbiosis, including its potential and its benefits, should be included in the education of engineers and business students to ensure the availability of a sufficient skill base. To accelerate commercial deployment, we encourage potential partners and facilitators in industrial symbiosis initiatives to proactively evaluate all financing options, to overcome the infrastructure investment hurdles and to encourage private investments. The European Commission should therefore evaluate the possibility of establishing suitable instruments to link promising R&I projects at an appropriate maturity level to investors and financing, to speed up the commercial deployment.
1 INTRODUCTION

1.1 Framework for industrial symbiosis

The understanding that the earth’s resources are limited has been growing exponentially since The Limits to Growth was published all the way back in 1972(1). Obviously, this applies to all resources that humankind is using to a different extent, and the approaches to mitigate resource limitations are very diverse, depending on the nature of the resources in question. Based on the well-known concept of reduce, reuse, recycle, the approaches include avoiding the use of a resource, reducing the need for the use of a resource, reusing the resource, recycling a resource and using waste as a resource, depending on the circumstances, the current understanding of the need and the possibilities available.

Apart from targeting the quantities of resources used through these approaches, reducing the negative impact of a resource used is obviously not just a matter of quantity. It is also important to consider the impact a resource has in terms of cost, availability, environmental impact, etc. and therefore, replacement of problematic resources by more sustainable ones is a priority.

There are many methods to reduce the impact of using resources. One approach is circular economy (often referred to simply as circularity, as exemplified by ‘Circularity Indicators– an approach to measuring circularity’(2)) as defined by Geissdoerfer et al. as an economic system aimed at minimising waste and making the most of the resources available. In a circular system, according to Geissdoerfer et al., ‘resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can [often] be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling’(3). This regenerative approach is in contrast to the traditional linear economy, which has a ‘take-make-dispose model’ (4) of production.

Therefore, on 2 December 2015, the European Commission put forward a package to support the EU’s transition to a circular economy. On 4 March 2019, the Commission reported on the complete execution of the action plan. All 54 actions included in the 2015 plan have now been delivered or are being implemented. This will contribute to boost Europe’s competitiveness, modernise its economy and industry to create jobs, protect the environment and generate sustainable growth’ (5).

Furthermore, the Organisation for Economic Co-operation and Development in its report Business Models for the Circular Economy states ‘Natural resources, and the materials derived from them, represent the physical basis for the economic system. Recent decades have witnessed an unprecedented growth in demand for these resources, which has triggered interest from policy makers in transitioning to a more resource efficient and circular economy. This report presents a typology of five circular business models that could support the transition to a more resource efficient and circular economy: circular supply, resource recovery, product life extension, sharing, and product service system models. It reviews the current market penetration and assesses the potential scalability of each business model. Environmental potential is also discussed, as well as risks and unintended consequences that could result from a more widespread adoption of these business models. The report provides a broad set of policy approaches

that could help alleviate some of the barriers that currently hinder the widespread adoption of circular business models\(^\text{(*)}\).

Within the realm of circular economy, **industrial symbiosis** is one approach. Traditionally, the most frequently used definition is by Chertow: ‘The part of industrial ecology known as industrial symbiosis engages traditionally separate entities in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities [often] offered by geographic proximity\(^\text{(*)}\).

In 2012, Laybourn and Lombardi offered a renewed definition of industrial symbiosis, which was accepted by the *Journal of Industrial Ecology*\(^\text{(5)}\).

This definition was summarised by Domenech et al. as follows: ‘**Industrial symbiosis (IS)** is a systems approach to a more sustainable and integrated industrial system, which identifies business opportunities that leverage underutilised resources (such as materials, energy, water, capacity, expertise, assets etc.)\(^\text{(*)}\).

Explaining this definition further, Domenech et al. write ‘**IS involves organisations operating in different sectors of activity that engage in mutually beneficial transactions to reuse waste and by-products, finding innovative ways to source inputs and optimise the value of the residues of their processes, for instance by using waste or by-products from one activity as an input for another activity**\(^\text{(*)}\).

Recently, in 2018, a European Committee for Standardisation workshop agreement on industrial symbiosis was reached, defining industrial symbiosis as ‘**Industrial symbiosis is the use by one company or sector of underutilised resources broadly defined (including waste, by-products, residues, energy, water, logistics, capacity, expertise, equipment and materials) from another, with the result of keeping resources in productive use for longer**\(^\text{(*)}\).

This latter definition of industrial symbiosis is used throughout this report.

From this it becomes clear that there is a need to go beyond optimisation at process and/or plant level, and to have a more **systemic approach** moving towards optimisation at multi-plant/cluster level and beyond (e.g. local communities). This is critical to achieve overall optimisation. A holistic approach is needed to achieve breakthrough improvements for resource and energy efficiency, which are necessary to move towards a zero-waste circular economy.

### 1.2 Objectives of this report

After the European Parliament and Council reached a political agreement on **Horizon Europe**, the next EU research and innovation framework programme (2021-2027) and the most ambitious to date with a proposed budget of EUR 100 billion (yet to be agreed at institutional level), in April 2019, the European Commission started preparing the implementation of the programme, in an intensive **co-design process**. This process – focused in particular on Horizon Europe’s second pillar, Global challenges and European

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\(^\text{(*)}\) Ibid., p. 20.

The purpose of this report is to offer:

- a review of current projects in the area of industrial symbiosis;
- insights from practitioners devising and implementing industrial symbiosis;
- policy recommendations, deriving from this review and these insights, for the European Commission and for potential future initiatives in industrial symbiosis as input for the preparation of the strategic plan for Horizon Europe.

1.3 Portfolio management and the approach for this study

The European Commission supports public funding projects in many areas. At the time of writing, the Directorate for Industrial Technologies, recently renamed as Prosperity, within the Directorate-General for Research and Innovation is simultaneously funding about 350 projects. The directorate expressed an interest in a clustering approach for its portfolio management of projects. Therefore, at the beginning of this study, all projects were analysed according to which cluster of projects they could be assigned to, making sure that the cluster would be suitable for a portfolio management approach. Subsequently, it was decided to focus on the industrial symbiosis cluster of projects. This report summarises this analysis with a focus on commonalities, best practices, barriers, benefits, impact and policy recommendations.

The abovementioned analysis yielded a cluster of 28 projects with involvement from 14 different industrial sectors funded by the Directorate for Prosperity, which are either current or were recently finished with an overall European Commission funding of approximately EUR 180 million. As well as studying the literature, the members of these projects were asked to answer a questionnaire and were invited to a workshop in Brussels on 25 June 2019. During the workshop, the answers to the questionnaire were reviewed, the relevant topics were further discussed and additional points added.

In addition, two established industrial symbiosis sites were visited during this study, namely Kalundborg and Smart Delta Resources (SDR). Findings and input from these visits are also included in this report.

Based on an advanced draft of the study report, a validation workshop was held in Brussels on 4 November 2019, with approximately 50 participants. During this workshop a number of additional ideas were added and the report was endorsed by the participants.


2 POLICY CONTEXT

2.1 2050 climate change, climate policy targets and paths to implementation

On 28 November 2018, the European Commission presented its strategic long-term vision for 2050 in its 'A Clean Planet for all– A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy’ communication: ‘The aim of this long-term strategy is to confirm Europe’s commitment to lead in global climate action and to present a vision that can lead to achieving net-zero greenhouse gas emissions by 2050 through a socially-fair transition in a cost-efficient manner’ (12).

In the 2030 climate and energy framework adopted by the European Council in October 2014 and revised in 2018, the following key targets were set for 2030.

‘The 2030 climate and energy framework includes EU-wide targets and policy objectives for the period from 2021 to 2030.

Key targets for 2030:

- At least 40% cuts in greenhouse gas emissions (from 1990 levels)
- At least 32% share for renewable energy
- At least 32.5% improvement in energy efficiency’ (13).

The newly elected President of the European Commission, Ursula von der Leyen, is committed to making these targets even more ambitious. ‘In a speech she delivered in parliament a few hours before her election, von der Leyen said that she intends to make climate and the environment top priorities in all EU policy areas. She pledged to strengthen the EU’s short-term goal on greenhouse-gas emissions from a 40% reduction by 2030 to at least a 50% cut, relative to 1990 levels. The EU will also take the lead in forthcoming international climate negotiations and will encourage other major economies to increase their ambitions by 2021, she said.... Von der Leyen is also set to announce a “Green Deal for Europe” in her first 100 days in office, which would include a law to make Europe carbon neutral by 2050. “I want Europe to become the first climate-neutral continent in the world,” she said.’ (14) These goals and targets are a clear encouragement to use all possible routes to cut CO2 emissions, reduce waste, foster circularity and strengthen industrial symbiosis.

The Directorate-General for Research and Innovation of the European Commission describes the following as one of its policy areas.

Climate action– decarbonising the economy: Putting in place policies and legislation to cut emissions, moving towards a low-carbon economy and fulfilling the EU’s commitments to the Paris Agreement on climate change’ (15).

The RECREATE project (REsearch network for forward-looking activities and assessment of research and innovation prospects in the fields of Climate, Resource Efficiency and raw mATErial)s made (among others) the following recommendations on priority areas for fostering innovation.

- ‘Fostering new, especially service-oriented business models and creating a market environment that allows sustainable businesses to thrive’;

‘Pushing for a circular economy by turning waste into a resource’(16).

The results of the work of the European Commission circular economy package, already mentioned above, are in many ways the basis for future efforts.

Currently, the European Commission is preparing the implementation of Horizon Europe. In preparation, a public co-design consultation process was put in place and culminated in the European Research and Innovation Days from 24 to 26 September 2019.

The Directorate for Prosperity within DG Research and Innovation funds numerous R & I projects to achieve current goals and targets and actively contributes to planning the implementation of Horizon Europe, taking into account the results of the strategic planning process and the new targets set out by the President of the European Commission. Therefore, the priority is to bridge the transition from the current Horizon 2020 programme to the upcoming Horizon Europe framework programme.

2.2 Circular economy, recycling, CO₂ emission reduction and industrial symbiosis

As already indicated in the introduction, the definition of the terms involved in the discussion of industrial symbiosis is not easy and often a source of confusion. Therefore, beyond the definitions given in the introduction, an attempt is made to show the hierarchy and relationship of these areas in a simple diagram, inspired by the point of view of the process industry (Figure 1).

![Figure 1. The hierarchy of terms involved in the discussion of industrial symbiosis](image)

Without going into the definition of each term in more detail, we conclude that industrial symbiosis is an important element contributing to establishing a circular economy. Industrial symbiosis, as an approach that looks at the ecosystem level, obviously goes beyond the optimisation of processes at the plant level (17).

Recycling is a building block, a mosaic piece that can be used in setting up a circular economy, but the scope of industrial symbiosis is broader, more ambitious and more complex, since multiple actors (industrial and/or public) must come together and develop a joint commercial, organisational, technological and ecological approach.

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3 PORTFOLIO OF EU-FUNDED RESEARCH AND INNOVATION PROJECTS

3.1 Project clusters in industrial technologies

The analysis of the 350 projects funded by the Directorate for Prosperity mentioned earlier showed that the projects can be easily clustered, which is necessary for a proper portfolio management approach. Of the bigger clusters in the portfolio, the top five are clearly related to the climate action area of responsibility for DG Research and Innovation. The project cluster for industrial symbiosis is the largest, containing 28 projects, indicating that the Directorate for Prosperity has already put significant effort and focus on supporting and funding industrial symbiosis.

3.2 The industrial symbiosis cluster of projects – symbiosis readiness level

These 28 projects were included in this study. To broaden the R & I project portfolio assessment with established examples of industrial symbiosis, the two industrial symbiosis sites Kalundborg and SDR were invited to take part. They participated in the questionnaire and the workshop and were included in the analysis.

Call topics of projects

These projects belong to 15 different topics in calls for proposals and are part of the Horizon 2020 work programmes, published between 2014 and 2017, as detailed below. This explains why they address quite different focus areas and indicates the broad support that industrial symbiosis receives from European Commission funding.

- SPIRE-02-2014: Downstream processing.
- SPIRE-01-2016: Water management systems.
- SPIRE-02-2016: Plant-wide monitoring.
- BIOTEC-06-2017: Optimisation of biocatalysis and downstream processing for the sustainable production of high value-added platform chemicals.
- WASTE-01-2014: Moving towards a circular economy through industrial symbiosis.
- EE-18-2015: New technologies for utilisation of heat recovery in large industrial systems, considering the whole energy cycle from heat production to transformation, delivery and end use.
- LCE-25-2016: Utilisation of captured CO₂ as feedstock for the process industry.

The detailed titles of the projects analysed are given in the appendix.

Technologies and tools covered in the industrial symbiosis cluster of projects

The following is a summary of technologies developed in the cluster of projects:

- CO/CO₂ conditioning and conversion to intermediates;
- pyro-hydrometallurgical process technology for alumina;
• methanol production technologies (catalyst, reactor, carbon capture);
• electrocatalytic technologies for converting CO₂ to added-value chemicals;
• separation, disinfection and chemical heat pump technologies for industrial water;
• borehole thermal energy storage technologies, artificial-intelligence-supported data management;
• process technology (reactor, electrodes, separation and purification) to obtain basic chemicals from lignin;
• distributed management and optimisation of coupled production systems;
• very large-scale electrolysis (gigawatt scale) for the production of sustainable hydrogen based on carbon neutral power;
• large-scale steam recompression to upgrade low-pressure steam to high-pressure steam;
• thermal processes, heat exchangers, thermochemical conversion;
• hydrolysis of lignocellulosic material and conversion to value chemicals;
• waste-heat-to-power and heat-recovery technologies;
• biotechnological process technology for CO₂ conversion.

The following is a summary of the current and future development needs for methods and tools:

• software for rapid screening of industrial symbiosis potential;
• virtual sector profiles (sector blueprints) for partnering in the process industry;
• generic industrial symbiosis cases;
• integrated solutions of demand-response and energy-aware-planning models and scheduling software, to drive in real time the flexibilisation of a single plant/company as a contribution to the optimisation of the overall cluster at a systemic level;
• life cycle sustainability assessment tools for assessing and optimising waste/by-product use across the network of different actors in different sectors;
• recommender systems for resource-need matching, multi-criteria decision support for energy conversion technologies, mathematical tools for decision support in symbiosis cost allocation and price setting;
• methodology and software platform to implement innovative industrial symbiosis.

The industrial symbiosis cluster of projects is an interesting group of projects consisting of two distinct subgroups: process technology projects and projects which develop tools and methodologies for fostering industrial symbiosis.
Maturity of a symbiosis, technology readiness level and symbiosis readiness level

It was attempted to determine what phase the projects or initiatives are in currently, their maturity with respect to implementing industrial symbiosis and their technology readiness level (TRL) ([18]) by asking specific questions in the questionnaire and discussing the matter during the workshop. In the answers to the questionnaire the TRL was specified, but during the discussion it became clear that the TRL alone does not suffice to describe the progress of an industrial symbiosis project properly. During the workshop, it was asked which hypothetical SRL the members of the projects thought they had reached. Figure 2 shows the results.

![Figure 2. Symbiosis readiness level as assessed by participants of the workshop for their projects](image)

The conclusion from this discussion is as follows.

**In order to assess the status of a project or a site (regional initiative) adequately, the status of the following different dimensions need to be considered separately:**

(1) technology,
(2) business,
(3) ecological, and
(4) managerial level of maturity.

If this is not done, the proper assessment of how far a symbiosis has to go before full implementation is reached is not reliably possible.

Therefore, **the following matrix is proposed in order to assess the status of an industrial symbiosis project or site comprehensively.** Progress in all four dimensions is usually required to reach a certain SRL. However, not all dimensions necessarily have the same importance and focus in a particular project or initiative. The concept of SRL might also be useful when assessing the readiness of regions or even countries. This matrix can serve as a checklist to assess progress realistically and has already proven helpful within the Kalundborg symbiosis.

<table>
<thead>
<tr>
<th>Symbiosis readiness level</th>
<th>Technology</th>
<th>Business</th>
<th>Ecology</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Commercialisation</td>
<td>Business case continuously controlled, reported and shared</td>
<td>Sustainability benefits proven</td>
<td>Resilient partnership</td>
</tr>
<tr>
<td>8</td>
<td>Extended operation</td>
<td>Finalise legal framework</td>
<td>Benefits routinely monitored and reported</td>
<td>Practical operation and management starts</td>
</tr>
<tr>
<td>7</td>
<td>Demonstration</td>
<td>Partners committed</td>
<td>Monitoring and reporting begins</td>
<td>Senior management is involved and supports industrial symbiosis case</td>
</tr>
<tr>
<td>6</td>
<td>Prototype demonstration ‘looks like’</td>
<td>Business case with all details</td>
<td>Permits applied for</td>
<td>Concept for joint management is developed</td>
</tr>
<tr>
<td>5</td>
<td>Breadboard demonstration ‘acts like’</td>
<td>Evaluate competitiveness</td>
<td>Sustainability assessment finalised</td>
<td>Partners start joint evaluation of industrial symbiosis. potential</td>
</tr>
<tr>
<td>4</td>
<td>Proof of concept validation</td>
<td>Check resources and criteria</td>
<td>Sustainability assessment in progress</td>
<td>Partners indicate interest</td>
</tr>
<tr>
<td>3</td>
<td>Proof of concept research (bench scale)</td>
<td>Check fit with strategies of partners</td>
<td>Thorough data collection</td>
<td>First contact with partners</td>
</tr>
<tr>
<td>2</td>
<td>Academic research</td>
<td>Develop concept</td>
<td>Rough estimate</td>
<td>Potential partners (*) identified</td>
</tr>
<tr>
<td>1</td>
<td>Initial ideas</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Proposal for defining the symbiosis readiness level

(*) Partners in this context means all stakeholders in the process of implementing industrial symbiosis, including e.g. the broader public, public authorities and industrial partners.

Concerning the narrower TRL, the projects within the portfolio of this study cover a broad spectrum, starting from TRL 3 and going up to TRL 7. Furthermore, many of the TRLs given are estimated or planned TRLs for the future end of the project. Only some projects have already reached higher TRLs. In particular, the established sites Kalundborg and SDR have reached TRL 9, and four other projects having already implemented industrial symbiosis have reached a TRL of 7 or 8.

The discussion at the workshop yielded the following two further major insights.

1. **Many projects are in early phases, developing technologies or methods for the future implementation of industrial symbiosis. Therefore, extra effort should be invested in identifying potential and supporting implementation.**

2. **The process of maturation of a project is not linear. In many cases, the development will have to restart when the business, technologies, societal framework or regulations change.**
3.3 Preconditions for industrial symbiosis, in particular methods, tools and technologies

How do industrial symbioses start?

In the CEN workshop agreement, ‘four common approaches to industrial symbiosis (that are not mutually exclusive) vary depending on where the onus for identifying and advancing opportunities lies:

(1) Self-organised: a bottom-up approach resulting from direct interaction among industrial actors, without external coordination. Expertise resides within the organisations with resources and opportunities; organisations identify, assess and advance opportunities themselves.

(2) Facilitated: wherein a third-party intermediary coordinates the activity, working with organisations to identify opportunities and help bring them to fruition. Facilitators (sometimes referred to as practitioners) work with the companies to identify, assess and advance opportunities; often the onus is on the facilitators to progress opportunities. Facilitator business models vary from commercial brokers to public investment networks and any combination thereof.

(3) ICT-supported: industrial symbiosis activity is supported by an ICT system to capture and manage data on resource availability and potential synergies. The onus lies with the software users, be they companies, other organisations or facilitators.

(4) Strategic or planned: a top-down approach where networks are formed following a central plan or vision that includes attracting new businesses to regeneration sites or purpose-built developments. The onus lies with the central body (often public sector) implementing the plan or vision’ (19).

In the workshop, it was felt that in almost all practically implemented cases, the symbioses started with a status in which industrial symbiosis did not play a role, and only after the partners worked in parallel for a time were the opportunities for industrial symbiosis identified and implemented.

This leads to the conclusion that if one wants to foster the development of industrial symbiosis in a targeted and accelerated way, it would be most effective to focus on established industrial operations that fulfil the preconditions for analysing the opportunities for industrial symbiosis.

Generally speaking, we observe that the steps involved in fully establishing an industrial symbiosis are often as follows:

(1) a simple exchange of a resource (see definition), according to the idea that ‘one partner’s waste is another partner’s raw material’;

(2) development of an awareness that a circular economy approach through industrial symbiosis is advantageous with respect to economics and/or resource optimisation and sustainability;

(3) the recognition that a fair and equitable joint business model needs to be established or developed.

The establishment of truly integrated, joint and potentially new business models is the last step in the development and usually the most ambitious. As will be discussed in

more detail in Section 3.4 on barriers, there are many hurdles to overcome, including legal and contractual issues and the development needed of mutual trust across company or organisational borders. In our view, only true win-win situations will be sustainable, specifically where it is clear for all parties involved that the symbiotic cooperation provides added shared benefits (economic, environmental, etc.) compared to the stand-alone cases. An indication of how ambitious these cases are is the fact that usually only cost savings are specified by the projects, and not joint or shared profits.

Overall, a longer-term perspective (of at least one decade) needs to be applied to achieve deep industrial symbiosis integration, if it involves a larger-scale or a complete site. This certainly requires appropriate planning, road mapping, facilitation, etc. One goal of this study is to facilitate the acceleration of this process.

Creating the preconditions, including technologies, willingness to engage in mutual discussions with potential partners, awareness of the opportunities, mutual trust and commitment to the concept is therefore a process that will take many years. This should be taken into account by funding bodies, municipalities, industrial symbiosis associations and the potential partners themselves.

As discussed in Section 3.5 related to promoting the implementation of industrial symbiosis, this finding needs to be taken into account to ensure a realistic and promising approach.

Preconditions for industrial symbiosis

The above finding brings up the question of which preconditions must be fulfilled to make the implementation of industrial symbiosis likely. Those identified during this study are discussed in more detail in the following.

Awareness and willingness to engage in mutual discussions with potential partners

It is clear that the engagement and motivation of stakeholders and their willingness to be open to the industrial symbiosis approach is a necessary condition to trigger cooperation in the first step. This factor is probably the most important one for broader adoption of the concept of industrial symbiosis. Industrial players are often not familiar with the concept, including the potential achievable benefits and how the barriers to cooperation can be overcome, which keeps them from seriously considering industrial symbiosis.

Therefore, Section 3.5 on promoting and facilitating industrial symbiosis has been included in this report.

The second element is the willingness to engage in open discussions with other industrial companies, who are potential partners of a future industrial symbiosis. This means that a culture of openness and cooperation needs to be developed. A case that exemplifies this point is the development of the SDR symbiosis, discussed in Section 3.6.

In reviewing the projects of this study, it becomes clear that, due to the increased awareness of industrial companies of the threats of climate change and the need for improved sustainability of industrial activities, the willingness of companies to engage in industrial symbiosis as one route to achieving improved sustainability is increasing. This also often happens under the threat of losing competitiveness, as can be seen in SDR due to the rise of shale gas exploitation in other countries.
Sectors amenable to industrial symbiosis

For the 30 projects and symbioses analysed on the basis of the returned questionnaires, the spectrum of sectors is remarkably broad. Sectors involved in the work of the projects include chemicals, polymers, petrochemicals/refining, engineering, iron/steel, mining, building, cement, minerals, energy/electricity, fuels, pulp and paper, ceramics, glass, water, transport and automotive. For the bio-related projects the sectors include biotechnology, chemicals, biomass, biochemicals, materials and catalysis.

This indicates that industrial symbiosis approaches can be broadly applied to many different industrial sectors.

Local proximity

For the industrial symbiosis cases studied through the questionnaire and the workshop, the finding is that local proximity is not a precondition of industrial symbiosis but it significantly facilitates its establishment. In Domenech et al., 25 networks with completed synergies and a defined network scope were analysed and 23 of them had either local or regional scope.

Fundamentally, local proximity is not mandatory and can mean different distances depending on context (e.g. 1 km as opposed to 20-50 km), and certainly depends on several factors (e.g. on the value of the material in question), but local proximity is advantageous for the following reasons.

- For many materials, logistics does not allow for larger distances to be covered, e.g. for steam and water, and cost usually increases with increased distance.

- Certain infrastructures, such as longer pipelines (e.g. for CO₂) may not necessarily be accepted by the public.

- Transport of resources is usually related to investment, cost (e.g. grid cost) and resource use (e.g. energy), which increase for longer distances, unless specific conditions are met (e.g. the pipeline or grid already exists). For this reason, distance is often an important factor to consider for the economic feasibility of symbiotic interactions. Therefore, the need for infrastructures should also be part of broader discussions involving local and regional communities and authorities at the relevant level (local, regional, national).

- Since mutual trust and the willingness to cooperate are important preconditions, these can be much more easily established if the partners are located close together and know each other from previous activities.

The established symbioses Kalundborg and SDR are both based on local or regional proximity.

Methods and tools for the identification of industrial symbiosis opportunities

Different approaches to identifying opportunities for establishing industrial symbiosis are used in practice. The most obvious approach is within an existing group of companies in local proximity, be it an industrial park or a more loosely arranged cluster, where the responsible actors already know each other to some extent. In these cases, be it through self-organisation or through facilitation of a third party, the question ‘Can we establish a symbiosis that will create mutual benefits and potentially a positive impact on sustainability and the environment?’ is asked.
In this context, some of the EU-funded projects included in this study have taken different approaches to addressing the challenge of identifying and establishing industrial symbiosis initiatives. Some notable examples are as follows.

'[Scaling European resources with industrial symbiosis (SCALER)] aims to massively increase the implementation of industrial symbiosis, by developing mechanisms to retain the embedded value of European resources, thus, enabling the circular economy to achieve higher resource efficiency through systemic innovations led by intensified industrial symbiosis initiatives and enhanced by cross-sectorial collaboration and, to support the development of a roadmap to improve the adoption of industrial symbiosis in the European process industry at regional / national / European level. SCALER will use new and advanced practices in identifying value opportunities, use new methods to create a larger market for available resources, and use new methods to measure and manage the implementation and sustaining of new relationships. SCALER brings together qualitative and quantitative tools and methods to support self-organised initiatives on industrial symbiosis and to enhance facilitation processes and coordination actions. The creation of new spaces for interaction, collaboration and cooperation and the engagement of a broader set of stakeholders are crucial elements of the multiplier effect in industrial symbiosis implementation. SCALER provides a comprehensive solution for understanding, assessing and intensifying the potential of industrial symbiosis in Europe' (20).

In SCALER, 1 000 theoretical combinations were identified and the 100 more-promising cases selected have already been analysed in more depth.

'The [enhanced energy and resource efficiency and performance in process industry operations via onsite and cross-sectorial symbiosis (EPOS)] project develops a simple and single management tool for exploring industrial symbiosis (IS) across process sectors. A wide range of technology and management solutions is proposed for supporting collaboration between sectors, by making industrial sites more efficient, cost-effective, competitive and sustainable... Using the U Gent cluster management surveys and the [École polytechnique fédérale de Lausanne (EPFL)] site optimisation platform, cluster sites were studied, references set, opportunities for cross-sectorial symbiosis spotted and IS potential was mapped for each EPOS cluster. [Several] IS pilot cases were investigated in detail including assessments of greenhouse gas emissions reduction, investments, cost savings, etc. These ‘cases served as industry-driven input for developing a realistic IS methodology and building the prototype of the EPOS toolbox’ (21).

The following achievements were reached: a ‘deep understanding is reached of all EPOS sites & sectors, building from the engineering & organisational solutions in the EPOS process industries, that resulted in long lists of potential IS and generic business cases for IS across Europe’ (22).

An ‘EPOS prototype IS toolbox has been developed ... The EPOS User Club is activated and shares all guidance material on IS prepared during the EPOS project and wider: manuals, technology watches, generic IS cases, background on methods and tools, training courses, etc’ (23).

The main focus of the EPOS project was the development of sector blueprints to solve confidentiality issues and to simplify the initiation of discussions.

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(20) CORDIS, ‘Scaling European resources with industrial symbiosis’ (https://cordis.europa.eu/project/id/768748).
(22) Ibid.
(23) Ibid.
In the SHAREBOX project, the ‘approach that underpins SHAREBOX centres on a logical workflow that covers from the identification of new symbiotic synergies right through optimised connections among companies and organisations in established symbiotic relationships ... SHAREBOX will provide plant operations and production managers with the robust and reliable information [through a data platform] that they need in real-time in order to effectively and confidently share resources (plant, energy, water, residues and recycled materials) with other companies in an optimum symbiotic ecosystem’ (24).

SHAREBOX delivered and facilitated notable industrial synergy projects and quantified the benefits gained from them.

‘[Human-mimetic approach to the integrated monitoring, management and optimization of a symbiotic cluster of smart production units (SYMBIOPTIMA)] developed an integrated Energy and Resource Management System (ERMS), which offers tools for production scheduling and demand response management and for Life Cycle Sustainability Assessments (LCSAs). It also created hardware for modular “plug and play” monitoring of production plants, as well as an integrated toolset for all thermal energy sources, flows and sinks. Additionally, to maximise the reuse of waste, it developed a unique de-polymerisation process for plastics (PET)’ (25). This includes a scalable network of low footprint sensors for process monitoring and control, as well as tools for energy-aware scheduling of operations in cross-sectoral operations (i.e. optimising multi-plant operation schedule based on availability and cost of energy).

Current and future development needs for methods and tools are significant, since these act as catalysts for the identification of the opportunity. These tools are very important in managing operations at a multi-company, multi-plant and multi-location scale – especially considering the much more complex future energy system, where flexibility and demand-response matching in real time will be more delicate. Based on the analysis of the projects in the scope of this study these tools are:

- software for rapid screening of industrial symbiosis potential, based on available resource streams and technologies;
- recommender systems for resource-need matching, multi-criteria decision support for energy conversion technologies, tools for decision support in symbiosis cost allocation and price setting;
- virtual sector profiles (sector blueprints) for partnering in the process industry (useful for informing, modelling and identifying opportunities);
- generic industrial symbiosis cases;
- integrated solutions of demand-response and energy-aware-planning models and scheduling software, to drive in real time the flexibilisation of a single plant/company as a contribution to the optimisation of the overall cluster at a systemic level;
- life cycle sustainability assessment tools for assessing and optimising waste/by-product use across the network of different actors in different sectors;
- methodology and software platform to implement innovative industrial symbiosis.

(24) SHAREBOX project (http://sharebox-project.eu/).
Developing technologies

As discussed, the identification of opportunities for concrete implementation of industrial symbiosis cases is not a trivial task. This is because, among other reasons, in some cases, the technologies which would allow partners to work symbiotically need to first be developed or adapted to the symbiotic interaction (e.g. pretreatment of waste streams to be used as raw materials, removal of contaminants and adaptation of the processes to different composition raw materials).

Many technologies are already available from non-networked applications and can be used to support industrial symbiosis concepts. Nevertheless, significant challenges arise from the current energy transition and the need for full circularity. As we pointed out during the discussion of the SRL, technologies—their availability or the need for their development—should be considered at the beginning of an industrial symbiosis initiative. In the future, design, development and optimisation of technologies should be oriented towards ensuring their usefulness in complex, cross-sectoral systems of industrial symbiosis.

The technologies that are the focus of current European Commission-funded projects, as mentioned earlier, are:

- CO/CO\(_2\) conditioning and conversion to intermediates;
- pyro-hydrometallurgical process technology for alumina;
- methanol production technologies (catalyst, reactor, carbon capture);
- electrocatalytic technologies for converting CO\(_2\) to added-value chemicals;
- separation, disinfection and chemical heat pump technologies for industrial water;
- borehole thermal energy storage technologies, artificial-intelligence-supported data management;
- process technology (reactor, electrodes, separation and purification) to obtain basic chemicals from lignin;
- distributed management and optimisation of coupled production systems;
- very large-scale electrolysis (gigawatt scale) for the production of sustainable hydrogen based on carbon neutral power;
- large-scale steam recompression to upgrade low-pressure steam to high-pressure steam;
- thermal processes, heat exchangers, thermochemical conversion;
- hydrolysis of lignocellulosic material and conversion to value chemicals;
- waste-heat-to-power and heat-recovery technologies;
- biotechnological process technology for CO\(_2\) conversion.
These areas should continue to be developed and supported in order to ensure their broad availability for partners willing to engage in industrial symbiosis. Summarising the main areas of need for technology development leads to the following.

- **CO₂ capture, storage and reconditioning technologies.**

- **Electrification of processes** and optimisation of energy and resource utilisation at system level (e.g. electrochemical processes and utilisation of electrified technologies in processing, such as microwave, plasma and photocatalysis).

- **Large-scale electrolyzers** and non-conventional energy sources to enable processes for integration in a renewable energy grid.

- **Process technologies for the efficient production of flexible energy storage carriers** (e.g. methanol and hydrogen).

- Novel **purification technologies** to enable the utilisation of waste streams as secondary raw materials in industrial processes (e.g. purification, dismantling and recycling technologies) to **upgrade process residues for reuse.** Technologies to provide a more **efficient utilisation of water** in industry, aiming to reduce freshwater utilisation and achieve a closed loop.

- **More efficient heat-recovery technologies.**

- **Technologies for the utilisation of renewable energy** in industry (e.g. concentrated solar energy).

- **Biotechnological technologies**, e.g. for CO₂ conversion and use of biological substances like lignin for the production of value chemicals.

- **Lifecycle and holistic approach** in product and process design (i.e. thinking about the end of life of a product and the waste stream of a process).

### 3.4 Barriers to implementing industrial symbiosis

Industrial symbiosis is not currently the prevalent mode of operation for industrial companies. Therefore, **many barriers have to be overcome** to foster the adoption of this new paradigm successfully. Many of them have been discussed before but were again clearly identified during the course of this study.

Companies usually focus on their **profitability and competitiveness.** For this, procurement will seek out suppliers who make the best offers, often at the lowest cost. Therefore, in order to motivate waste owners (e.g. CO₂ emitters) to make these streams available, the **culture of shared benefits**, which is the hallmark of industrial symbiosis, first needs to be established, even if at the beginning, it might be perceived as counterproductive for the welfare of a company. Even more, a **culture of trust** between independent industrial actors needs to be established.

Establishing industrial symbiosis also requires certain **investments**, for example in **new technologies, new infrastructure, the operation itself and the time needed.** These investments will often only be made when the benefits are certain, clear and short-term. In this context, if industrial symbiosis is to be promoted, there is certainly the need for broader involvement of local and national authorities, especially in major infrastructure investments (e.g. in pipelines and grids).

Furthermore, **antitrust, legal and IP-protection rules** are significant barriers and extra effort needs to be made to meet the challenges. This pertains specifically to the **exchange of data**, be it technical or commercial. Not only is such an exchange potentially problematic because of antitrust rules, but also often not even wanted by the industrial partners. When data exchange is intended, proper confidentiality agreements
need to be in place to avoid potential leaks and damage to the partners. The question arises of who the (neutral) data holder should be. In this context, modern digital tools like blockchain technology might be helpful since they are commonly used as a solution in situations where trust between partners is an issue.

A lack of awareness and understanding of industrial symbiosis, a lack of visibility of opportunities and a lack of relevant skills and successful business models slow down the adoption of industrial symbiosis.

Clarity, stability, consistency and a long-term perspective on the regulations to utilise waste as a raw material are an important factor. Harmonisation of the regulations can also be an important point, especially for cross-border utilisation of waste. Another issue is the EU emissions trading system, where some emitters do not feel encouraged to bring forward the emissions to be reused because of the pricing. This is clearly a policy issue that needs to be addressed.

It will also be helpful to establish markets for products like fuels of non-biological origin (e-fuels) and recycled carbon fuels.

For the identification of industrial symbiosis opportunities, relevant data on waste streams, their classification, composition and quantities need to be publicly available. In the same way as do, for example, data on infrastructure for transport and logistics gas, electricity and energy. This is not usually the case. Lessons learned from the regulation of big data should be applied to industrial symbiosis. The standardisation of the data is an important factor. Municipalities should find a way of making, for example, data on waste streams publicly available in an accepted way. Therefore, we propose establishing data and information exchange platforms. This would be very much in line with a strong move towards adopting the principles of Industry 4.0 (i.e. the transformation of manufacturing through the merging of digital and internet-of-things technology with manufacturing).

Generally speaking, standardisation has played a leading role in creating the EU single market. Standards support market-based competition and help ensure the interoperability of complementary products and services. They reduce costs, improve safety and enhance competition. Due to their role in protecting health, safety, security and the environment, standards are important to the public. The EU has an active standardisation policy that promotes standards as a path to better regulation and enhancing the competitiveness of European industry.

Furthermore, the SPIRE PPP has recently published a position paper on the increased use of artificial intelligence in the process industries (26). As also indicated by the projects SHAREBOX, fostering industrial symbiosis for a sustainable resource intensive industry across the extended construction value chain (FISSAC) and sustainable production of industrial recovered energy (SusPIRE), artificial intelligence can be an important step towards obtaining data on potential symbiotic cooperation more efficiently and without human intervention.

In this context, it has become clear that the future use of digital tools will have to be seriously considered. For instance, for the day-to-day operation of production, it will be necessary to use advanced modelling to better cope with the different operational characteristics in different industrial sectors, such as different temperature thresholds and renewable energy supply fluctuations. For this purpose, a technology like digital twins (27) will be useful.

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3.5 Promoting industrial symbiosis

Given the many barriers to the full implementation of industrial symbiosis, a number of building blocks are considered important to achieving progress.

One important consideration is the fact that **industrial symbiosis business cases are usually supply driven**, rather than customer-demand driven like most of the economy. Therefore, the availability of a waste stream as an attractive raw material has to be identified and promoted to potential users. This is a fundamentally different approach to the customary marketing of products based on an identified customer need. It essentially reverses the traditional commercial thinking and also changes the approach to innovation. Therefore, different approaches have to be used for industrial symbiosis, most of which are not familiar to industrial partners. Nevertheless, in the future, a **demand-oriented forward-thinking approach** in designing businesses, cooperation and processes should be applied to make industrial symbiosis more of a by-design approach.

There is a need to provide **better visibility and successful examples** because this will create motivation to consider a symbiotic cooperation. Establishing pilot and demonstration cases of first-of-a-kind industrial symbiosis implementations would show the potential in terms of greenhouse gas emissions reduction and circularity, and also the advantages for competitiveness.

**Site ecodesign**

In the EU ecodesign directive (28), the EU ‘provides consistent EU-wide rules for improving the environmental performance of products’ (29). These design criteria could also be applied to the concept of **site master planning and site development**. Though the number of new industrial sites being developed in Europe is small, constant adaptations and improvements are common and provide opportunities to use ecodesign criteria and therefore foster the implementation of industrial symbiosis.

‘Suren Erkman proposes 4 strategies for restructuring the production system:

- Circulation of material and energy flows as much as possible;
- Dematerialize the economy;
- Make processes more efficient to reduce dissipative loss;
- Make energy sources carbon-free’ (30).

**FISSAC living labs and open innovation test beds**

These two concepts are closely related and therefore fundamentally propose a similar approach as is clear from the following.

**FISSAC living labs**

‘A living lab (LL), in contrast to a traditional laboratory, operates in a real-life context with a user-centric approach. The physical and/or organisational boundaries of a living lab are defined by purpose, scope, and context. The scope, aims, objectives, duration, actor involvement, degree of participation, and boundaries of a living laboratory are open

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for definition by its participants... [The] following elements tend to be core features of a living laboratory:

- Experimental approaches in real-life context
- Participation and user involvement
- Collaboration and co-production of knowledge

From a methodological perspective, today’s living labs are networks composed of heterogeneous actors, resources, and activities that integrate user-centred research and open innovation (Leminen et al. 2012). From the infrastructure perspective, they can be seen as facilities that enable experimentation and co-creation with users in real-life environments (Sundramoorthy et al. 2011)... Within FISSAC nine regional living labs will be established with their own defined purpose and scope. The living lab leaders will engage actors from the construction industry value chain to identify appropriate challenges related to industrial symbiosis in their regions. Through purposely designed meetings their collaborative knowledge and experience will then be used to understand how these challenges can be addressed’ (\(^\text{11}\))

**This concept, which within the FISSAC project is focused on the construction industry, could be extended and applied to industrial symbiosis constellations in other industries.**

**Open innovation test beds**

‘Open Innovation Test Beds are entities, established in at least three Member States or Associated Countries, offering access to physical facilities, capabilities and services required for the development, testing and upscaling of nanotechnology and advanced materials in industrial environments. The objective of the Open Innovation Test Beds is to bring nanotechnologies and advanced materials within the reach of companies and users in order to advance from validation in a laboratory [(TRL 4)] to prototypes in industrial environments [(TRL 7)].

Open Innovation Test Beds will upgrade existing or support the setting of new public and private test beds, pilot lines, and demonstrators to develop, test and upscale nanotechnologies and advanced materials for new innovative products and services in some specific domains.

They will be typically run by for profit organisations. Users could be industrial, including [small and medium-sized enterprises (SMEs)], as well as innovators and start-ups’ (\(^\text{12}\)).

**This concept, which is currently focused on nanotechnology and advanced materials, could be extended and applied to industrial symbiosis constellations in other technology areas.**

**Facilitation**

In summary, from the analysis of the project portfolio and the established industrial symbiosis initiatives, it appears that well-organised facilitation is the best basis on which to promote industrial symbiosis and drive its implementation with optimum speed. Given the difficulties in identifying the opportunities, creating the necessary awareness in the


potential partners, including municipalities and regional and local authorities, and the significant time needed overall for the process, a catalysing body to speed up the process is a big advantage. For a facilitator to be effective, **the facilitator needs to be neutral and have a proper mandate** from the potential partners, since their activities will often be perceived as disruptive and unconventional.

Furthermore, for major infrastructure investments (e.g. large electrolyzers, pipelines and grids) **broader cooperation** might be needed (industry, regional/national/European authorities, local communities) and longer timelines, roadmaps and investment plans should be put in place.

A number of actors could be suitable facilitators. One approach would be to give the facilitator role to the **industrial park owner/operator**. Companies in an industrial park are used to receiving overarching services from the park owner/operator and could give them a mandate to facilitate the establishment of industrial symbiosis. Furthermore, since new infrastructure and infrastructure services often need to be established and operated, these are obvious candidates.

Another option is to give the role to the **municipality or the chamber of commerce**. These players are usually regarded as neutral and are interested in the prosperity, sustainability and growth of the industrial community. This approach would also recognise that regions can be affected positively and should therefore help establish industrial symbiosis as a factor for growth. In cases of industrial symbiosis nearing realisation, local authorities usually play an important role as supporters, facilitators and partners and, as experience shows, are usually open to the approach.

One approach would give the role to the **association** of a cluster of companies and would have to be actively established by the partners involved. This is an advanced step, since it requires the prior conviction that industrial symbiosis has the potential to create benefits for all involved. SDR is again a practical example of this.

Another approach would be to use the **hubs for circularity**, proposed by the **SPIRE PPP**, as the vehicle to promote industrial symbiosis. The concept described in the following is oriented towards improving visibility and providing successful examples in order to accelerate the acceptance of the concept of industrial symbiosis, by addressing the need for a large-scale first-of-a-kind demonstration of industrial symbiosis and circularity in industry. ‘A SPIRE “Hub For Circularit”y is defined as a cluster of interconnected industrial (large companies and SMEs) and/or public facilities within a given geographical area, which collectively achieve a demonstrable level of circularity and carbon neutrality in their use of resources (including feedstock as well as energy and water) whilst boosting the global competitiveness of the EU Process Industry and sustainable growth’ (\(^{(33)}\)).

This would have the advantage that a PPP like SPIRE is already an established, recognised and organised entity and the hubs would address another important point highlighted in the projects’ assessment: so far, individual symbiosis partnerships have had to do most of the promoting individually, i.e. in an uncoordinated way.

We propose to establish a **community of practice** for industrial symbiosis which could be an entity with a mandate to promote and enhance industrial symbiosis, identify **best practices**, communicate its **benefits** and help in **educating** and establishing industrial symbiosis. This community would also allow different industrial symbiosis sites to share **knowledge and experience** and to mutually benefit from the insights that other sites have gained during the period of establishing the symbiosis. The community could publish a set of industrial symbiosis guidelines in a **handbook, which would help drive the understanding and acceptance** in an accelerated way. It could also run a platform to share experiences and technologies helpful in building the cooperation necessary for industrial symbiosis. This community could also develop an **up-to-date inventory** of

industrial symbioses and of opportunities for cross-sectoral cooperation. It could be used for the design of site (clusters) and regional planning in Europe and beyond.

When facilitating the implementation of industrial symbiosis, the tools developed by projects like SCALER and SHAREBOX and industry blueprints developed by the EPOS project will prove useful. New tools for the evaluation of business cases are probably not needed, since commercial viability will still be based on the viability of a new joint business case, which can be determined with traditional analyses.

3.6 Specific insights from the Kalundborg Smart Delta Resources symbioses

Kalundborg

During a visit to the Kalundborg symbiosis and discussions with a number of the parties involved in the symbiosis, many insights were shared that can also be helpful to the broader community.

The history of the symbiosis in Kalundborg began in 1961 with plans to use water from Lake Tisso for industrial purposes. Today, in Kalundborg the waste water from the industry is used for biogas production, heat pumps for district heating and there is a discussion to look into phosphorus and nitrogen removal and production ... The Kalundborg Utility is involved in three main types of water streams in the Kalundborg symbiosis. First, the utility supplies treated and untreated surface water in two qualities from Lake Tisso to Novo Nordisk and Novozymes (pharmaceutical and enzymes factories). By using surface water, the scarce groundwater resources are preserved. Second, the utility receives industrial and household wastewater, which is cleansed at one of Europe’s most advanced wastewater treatment plants in Kalundborg. Here, complex wastewater from the industry can be treated in one of the many specialized processes including an ozone plant and moving bed biofilm reactor (MBBR) technology. The ozone plant was built in 2002 and it was co-financed by Novozymes and Novo Nordisk. At the time, it was necessary to make use of this best available technology to comply with legal requirements to the discharge quality. The industry has since then developed their pre-treatment of the wastewater, and today Kalundborg Utility only runs the ozone plant during rare peaks’ (34).

The partnership in Kalundborg is organised as a private association, run by a board of directors, which meets approximately four times a year. All members have a seat on the board and pay an annual fee to the association. The secretariat of the association was run by the municipality for a long time, securing long-term facilitation and continuity of the partnership. Since April 1st 2019 it has become an independent entity. The secretariat, called Symbiosis Center Denmark, is involved in a number of different projects, mainly addressing SMEs both in the region and outside Denmark. This is very much in line with the earlier finding that the commitment and engagement of the partners and their investment in the symbiosis are crucial for its success. In 2017, the association agreed on a mutual vision to become the world’s leading industrial symbiosis with a circular approach to production, by renewing the partnership, implementing a minimum of 10 new projects before 2025 and sharing knowledge with others. The motto ‘Systems make it possible, people make it happen’ underlines this notion.

For example, Novo Nordisk recently adopted a ‘circular for zero’ strategy and is therefore strengthening its commitment to the symbiosis, for instance by holding the chairmanship of the board.

Even before the introduction of this strategy Novo Nordisk established cooperation with the Asnæs Power Station, run by Dong Energy, which will supply green energy to Novo

Nordisk, Novozymes and district heating customers in Kalundborg. The shift from coal to wood chips at Asnæs Power Station will result in an annual reduction in CO₂ emissions of around 800,000 tonnes (35).

In a new biogas plant, inaugurated in June 2018, the companies Ørsted and Bigadan will be converting the by-products of the factories of Novozymes and Novo Nordisk in Kalundborg into biogas, which will then be upgraded to natural gas. After the degassing, the biomass will be utilised as fertiliser in the fields (36).

For the municipality and the community, attracting talent, in particular engineers, to a community with only 50,000 inhabitants, but with 80,000 jobs in the wider symbiosis, is an important success factor. Therefore, the Knowledge Hub Zealand plays an important role in the education of the technically oriented workforce, for example biotech engineers. The Kalundborg symbiosis actively supports this effort, as well as giving start-ups and technology-driven SMEs access to the potential streams in the partnership, creating new business opportunities.

In the discussions during the visit to Kalundborg, it also became clear that support for the establishment of pilot and testing facilities for the development of technologies needed to advance the symbiosis, for example through public funding, would be highly welcome and necessary to unfold the potential of all available streams in the existing symbiosis, taking the ecosystem from an analogue level to explore the possibilities of Industry 4.0.

Smart Delta Resources

SDR is a much younger example of industrial symbiosis, officially established in 2014. The symbiosis is formed of 12 companies from the provinces of Zeeland and West Brabant in the Netherlands, and the province of East Flanders and the harbour of Antwerp in Belgium. At the beginning a neutral and confidential broker ECN (Energy research Centre of the Netherlands) was hired to identify the potential for cooperation in the existing cluster of industries and sponsored by the municipalities. It was clear to the partners that facilitation (as discussed earlier in this report) was essential and, therefore, the umbrella organisation SDR was established. Today it has a budget of about EUR 500,000 per year, mainly provided by the companies involved and co-sponsored by the provinces and harbour authorities. The umbrella organisation consists of six individuals. The facilitation effort is considered the element ‘that keeps the symbiosis moving’. Here also, the local proximity, though with a radius of approximately 30 km, is considered the basis for the symbiosis. Furthermore, the partners involved come from different sectors and are not competitors. It is the firm belief of the partners that the companies involved need to be open to cooperation and engaged and committed at the highest level to ensure success. Although the symbiosis is still young, the partners consider the typical timescale for full integration through industrial symbiosis to be about 10 years.

One project is concerned with the hydrogen produced in DOW’s various naphtha crackers. This hydrogen is currently partly used as a reactant in the DOW Terneuzen production processes, while the surplus is used to fuel the production processes. However, this does not constitute an optimal use, as the companies Yara and ICL-IP can better use this hydrogen as a raw material in their production processes. To allow this symbiosis, the transport of hydrogen per an already existing underground pipeline (GTS gas transport pipeline) has been implemented in this project. This pipeline was modified to link the three plants, providing a win-win situation for all partners involved in the project. In the first stage, 4.5 kton of high quality [H₂] per year [corresponding to CO₂

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savings of about 10,000 tonnes of CO$_2$ per year, if this hydrogen were produced from fossil feedstocks] is provided to Yara and ICL-IP, which currently consumes hydrogen for the production of hydrogen bromide. The expectation is that the demand for [H2] will increase in the coming years. Hydrogen was previously only delivered by truck. ICL-IP is therefore benefiting from the hydrogen link between Dow and Yara (\textsuperscript{13}).

In the SDR roadmap, also, a plan for a \textbf{regional CO$_2$ network} is outlined. 'The main objective of the trajectory that starts with this project is the realisation of a CO$_2$ network connecting CO$_2$ sources in the Delta region to a network for storage through carbon capture and storage (CCS) and/or to users of CO$_2$ through carbon capture usage (CCU) technologies. This is an important condition to allow for a climate-neutral industry in the Delta Region: in most scenarios a significant CO$_2$ production will continue in the decades to come, for which CCS/CCU will be necessary. The Delta region does not have suitable storage options, so integration with the development of infrastructure (pipelines and storage facilities) in Rotterdam for example, are a crucial driver for this project. Given the momentum of these developments in the Netherlands, the long development time of such a large-scale infrastructure, and the impact on other projects make this project a key priority in this Roadmap. The scope also includes infrastructure options for CO$_2$ utilization (e.g. Steel2Chemicals).

The main objective of a full-scale CO$_2$ network will be reached in five steps:

1. Pre-feasibility study.
2. Trace study, inclusion, costing, impact on other infrastructure, ...
3. Phasing of plan, including alignment with capture options and storage and/or utilization options.
5. Completion of full network' (\textsuperscript{18}).

Other \textbf{projects} and technologies that are considered important for the future progress of the symbiosis are:

- robust and cost-effective electricity network infrastructure development;
- Power2Hydrogen in the Delta region;
- region H$_2$ open network infrastructure;
- circular feedstock plastics production;
- heat recovery, stimulation of heat-pump technology at SDR companies;
- geothermal potential in Bergen op Zoom;
- Steel2Chemicals (\textsuperscript{19}) (valorisation of steel-production gaseous emissions into added-value streams).

In the roadmap, it is clear to see that CCU and CCS will have a major role to play in the effort to reduce SDR’s overall CO$_2$ emissions by 90% by 2050.

For SDR, the **regional development** aspect is also significant, since the province of Zeeland only has 380,000 inhabitants and very much relies on the **competitiveness** and success of the industrial companies cooperating in SDR. For that reason, cooperation with the University of Utrecht to foster the education of engineers is part of the overall effort.

4 IMPACT OF RESEARCH AND INNOVATION FUNDING ON EU POLICY GOALS

4.1 Benefits of industrial symbiosis projects

In our study using the questionnaires we elicited input on benefits related to a number of areas that directly relate to policy priorities. In the following we comment on the answers and summarise findings for each of these areas.

**Reduction in energy used**

Almost all the projects studied have either led to a **reduction in energy used** or promise to do so when the project is finished. These savings fall into different categories. If a new production process is being developed, these new processes are more energy efficient. The second category leads to energy savings since energy is not wasted but used by another partner in the symbiosis. The savings range from 0% to 100% and very much depend on the individual case.

**Reduction in water used**

Interestingly, these projects do not specify water savings. The exception is Kalundborg, where surface water is replacing drinking water and recirculation. To increase the focus on the reduction of water use, a specific topic on water has been included in the **Horizon 2020 cross-cutting call** for proposals on ‘competitive, low carbon and circular industries’; the topic is ‘CE-SPIRE-07-2020: Preserving fresh water: recycling industrial waters industry’ (40).

The EPOS case study on industrial waste networks has focused on optimising water use in the process industry via water networks in industrial clusters. It was found that overall, a benefit of EUR 1-1.5/m³ of water exchanged could be realised (41). Probably even more important is the environmental benefit of saving 10-40% of the fresh water needed (42).

**Avoidance of residues as waste through reuse, recycling and circularity**

In the spirit of circularity, many projects are set up around the concept of using the waste from one process as the raw material for another one. One can even say that the majority of projects are built on this concept, rather than explicitly aiming at industrial symbiosis. Many of these reuse applications are also labelled as recycling, clearly demonstrating that the definitions are not used with sharp distinction. As is to be expected from Figure 2, in extension of reuse and recycling, circularity is often used as the headline. Here, CO₂ in particular is often involved and is a clear indication that this group of projects has addressed the need for a reduction of CO₂ emissions. This is in line with the **decarbonisation** focus that the European Commission has established in its policies.

Using the EPOS project’s case study on waste fuel valorisation, one can see that process industries have a high potential to better valorise their waste fuels. In the EPOS case

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study, it was found that the chemical industry on average has a calorific value of 9-10 kWh/kg of alternative fuel and the steel industry’s equivalent number is 8-9 kWh/kg. This is well above the minimum value needed to process fuels in cement kilns. The economic benefit of this use of the waste fuels would be about EUR 10-15/tonne of waste fuel and could lead to a 10-20% reduction of total operating costs (OPEX) for the cement industry(\textsuperscript{43}).

**Commercial benefits, cost savings and joint business cases**

As previously stated, the quantification of economic benefits, be it for the partners separately or joint benefits like shared profits, are difficult to specify. This is often only possible when implementation has already taken place. Many of the cost savings are actually energy cost savings, relating directly to the reduced energy usage discussed above. Nevertheless, almost all projects can give a cost savings estimate, mostly in the range of 20 to 80%. When longer-term operations are targeted, joint investments become necessary.

The EPOS project identified estimated overall reduction and savings potential and two of the examples were used above.

The SHAREBOX project analysed the expected sustainability impacts and benefits of using SHAREBOX’s secure ICT platform to facilitate 11 synergies. A potential global warming reduction of 74.8%, a total material consumption reduction of 23.2% and a waste reduction of 27% are predicted. As a consequence, an additional revenue from cost savings and new sales of about EUR 30,000,000 and the creation of 48 new jobs within 4 years is expected(\textsuperscript{44}).

**Job creation and skills**

In established industrial symbiosis cases and in industrial symbiosis projects, the creation of new jobs is evident or clearly foreseeable. For established cases, the drivers for the implementation are growth of the businesses involved, improvement of the sustainability of the operations and new business development. All these drivers create new jobs. Beyond that, the operation of the symbiosis will also create a certain need for new jobs, though this only applies to larger symbioses, such as Kalundborg and SDR.

During the phase when new technologies for future implementation in an industrial symbiosis are developed, the research, innovation and development activities themselves create additional activities and employment. This is also often true for mature technologies at high TRLs (i.e. 9), because, as previously mentioned, their SRL might be significantly lower and therefore significant work is needed to adapt them to the symbiosis scenario in which they are to be deployed.

Interestingly, we believe that the benefits for SMEs are particularly important, since they can react more flexibly to the new circumstances in an industrial symbiosis, i.e. offer the new tools and services needed (e.g. specific expertise in spotting opportunities, dedicated ICT tools and support to establish the business concept).

With the need for new technologies, new processes, new business models, new workflows and new services in order to establish, implement and run industrial symbiosis, the potential for new start-ups in this domain is generally considered to be high.

As already mentioned, one very important and intensely debated topic is facilitation as a catalyst for the creation of awareness, identification of the opportunities and joint

\textsuperscript{43} SPIRE 2030, ‘Enhanced energy and resource efficiency and performance in process industry operations via onsite and cross-sectorial symbiosis’ (https://www.spire2030.eu/epos).

\textsuperscript{44} SPIRE and SHAREBOX project, ‘SHAREBOX: Secure management platform for sharing process resources’, p. 3 (https://www.spire2030.eu/sites/default/files/users/user85/9.%20SHAREBOX_OK_0.pdf).
implementation of industrial symbiosis. This function would almost certainly mean new jobs for a neutral, independent and trusted party. This provides a good example of a potential new job linked to the specific requirements and skills (technical, regulatory, business related, etc.) necessary for industrial symbiosis. Furthermore, considering the importance of the local and regional context in establishing such cooperation, it is likely that, along with industrial symbiosis, many of these entities would develop in different European countries and regions.

Beyond the new business models and the opportunity for job creation, increasing the competitiveness of the companies is another key benefit which industrial symbiosis can deliver, thereby allowing jobs to be retained in Europe, which is of critical importance. The participating companies are convinced that extensive cooperation enables smart solutions to the international competitive disadvantage and loss of employment resulting from the disadvantaged position [in Europe] with regard to the availability of energy and commodities.(45)

In addition, the potential and the benefits of industrial symbiosis should be included in the education of engineers and business students. Since industrial symbiosis is a new approach, it would make progress much easier if already educated students were to enter the workforce well-prepared and familiar with the concept of industrial symbiosis, bringing with them the skills needed to identify opportunities, develop business cases and drive implementation. We also propose to include industrial symbiosis as a topic in the methodology developed by the energy audits in SMEs (Erasme) project to foster skills in energy efficiency.

In this context it is worth mentioning the ongoing blueprint for sectoral cooperation on skills initiative (“). Furthermore, all industrial symbiosis topics in the cross-cutting call include a specific point for impact on, for example, developing learning resources linked to industrial symbiosis.

**Investments, especially in SMEs, research and innovation and financing**

Since the realisation of industrial symbiosis usually necessitates investments, there is obviously the question of where the investments will come from. When the business case is clear and sound for the industrial partners, they will probably make the investments themselves. Therefore, driving industrial symbiosis will also mean **encouraging private investment** in industry so that it happens earlier and the overall process of adapting industrial symbiosis is **accelerated**.

Nonetheless, this may not always be the case. If significant new infrastructure between industrial partners, new services, new SMEs or new spin-offs needs to be established in order to seize the potential opportunity for industrial symbiosis, other strategies and sources of financing should certainly be considered.

**Sustainable finance** refers to a ‘broad range of financial approaches and instruments (see below) that are not based solely on economic criteria but also simultaneously and systematically on sustainability criteria (often on environmental, social and governance - ESG- criteria). These include aspects such as reducing environmental and climate damage, promoting social participation and good corporate governance’(47). There is currently a significant push to change the paradigms for financing criteria, from merely growth-based ones to growth- and sustainability-oriented ones. Therefore, opportunities to leverage funding through sustainable finance are likely to increase significantly in the coming years.

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Socially responsible investment is a generic term for a number of very different investment concepts. These include strictly sustainable investments, which in some cases fulfil 200-300 ecological, social and ethical criteria, including responsible investments, in which disputed sectors such as the defence industry are excluded or other concepts apply. The objective is to avoid contributing to violations of international standards and to interact with companies accordingly.

As discussed, industrial symbiosis is a way to improve sustainability and resource efficiency in industrial activities, as well as to foster a better integration of industry with local communities. Industrial symbiosis could therefore be used to promote a people-friendly industry and thereby improve industry’s image and acceptance among the broader public. This element should be strongly promoted when presenting the industrial symbiosis concept in the public arena. There is a growing interest from philanthropic institutions like the Novo Nordisk Foundation in supporting ‘scientific, humanitarian and social purposes’ and therefore, these institutions should also be considered when seeking funding support.

When trying to identify suitable investors, it might be advisable to approach investors who are interested in secure, long-term and ethical investments rather than speculation or short-term returns. This could be the case, for example, for pension funds looking for socially responsible and sustainable investment opportunities.

Furthermore, banks and other private investors might not be familiar with industrial symbiosis. They should be targeted with appropriate marketing efforts where successful examples are highlighted, to raise awareness of industrial symbiosis as a viable investment.

In February 2019, the European Investment Bank (EIB) made the following announcement. ‘The European Investment Bank has announced that it will boost financing for climate change mitigation and adaptation projects to 35% of its total investments in developing countries by 2020, up from 30% in 2018.

Announcing the corporate operational plan for 2019, EIB President Werner Hoyer noted that, “digitalisation, SMEs, education and skills, sustainable energy and the modernisation of infrastructure are crucial for the European economy to keep pace with global competition”.

The bank intends to invest a total of around €70 billion in 2019 in projects that will support the EU’s policy aims, with climate action at the forefront. The EIB is the world’s largest multilateral financier of climate projects, and has recently launched a lending review to further adapt its financing plans, which included a public consultation.

Hoyer also announced the bank’s intention to lead the way globally in sustainable financing, noting that the Green Bond market– first launched by the EIB in 2008 – is now worth €450 billion. In 2018, a Sustainability Awareness Bond was launched and raised €500 million for investments to support the UN’s Sustainable Development Goals. The first round of projects to be funded will focus mostly on water, but will expand to the remaining SDGs in the next rounds.

In addition, ‘The EU’s largest National Promotional Banks and Institutions and the European Investment Bank [launched] a EUR 10 billion initiative to accelerate the transition to a sustainable and circular economy… Five European national promotional banks & institutions and the European Investment Bank (EIB) launched today [18 July 2019] in Luxembourg the Joint Initiative on Circular Economy to support the

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development and implementation of circular economy projects and programmes in the European Union (EU). This flagship partnership will target at least EUR 10 billion of investments over the next five years (2019 – 2023). The aim is to prevent and eliminate waste, increase resource efficiency and foster innovation by promoting circularity in all sectors of the economy ... The joint initiative will focus particularly on investments in the EU Member States that will help accelerate the transition to a circular economy. It will target all stages of the value chain and lifecycle of products and services:

- Circular design and production: applying “reduce and recycle” strategies to design out waste at the source, prior to commercialisation.
- Circular use and life extension: enabling the reuse, repair, repurposing, refurbishing or remanufacturing of products in use phase
- Circular value recovery: recovering materials and other resources from waste, recovering waste heat and/or reusing treated wastewater
- Circular support: facilitating circular strategies in all lifecycle phases, for example with the deployment of key ICT technologies, digitalization and services supporting circular business models and circular value chains’ (51).

Information on EIB financing initiatives for circular economy projects can be found on the EIB website (52), where an example of a paper factory in Zaragoza is also provided (53).

Furthermore, InnovFin Advisory of the EIB has commented on access-to-finance conditions for projects supporting circular economy in its 2015 report, prepared for Commissioner Carlos Moedas. Therein, one of the major findings was that a ‘systemic and integrated approach is needed in order to accelerate the transition to a circular economy’ (54).

The Innovation Fund should also be seriously considered. It is ‘one of the world’s largest funding programmes for demonstration of innovative low-carbon technologies’ (55) and therefore ideally suited to support investments in pilot and demonstration infrastructure which often quickly reach the level of tens or even hundreds of millions of euros.

We encourage all potential partners in industrial symbiosis initiatives and facilitators to evaluate all financing options, to overcome the infrastructure investment hurdles mentioned earlier in this report in a proactive way.

In this context, the coordination and support action (CSA) project synergic circular economy across European regions (SCREEN) is a relevant point of reference:

The general objective of the project was ‘the definition of a replicable systemic approach towards a transition to Circular Economy in EU Regions within the context of the Smart Specialization Strategy. SCREEN also deals with the identification and implementation of operational synergies between investments in research and innovation under Horizon 2020, the Structural Funds and the European Investment Funds.

The project has developed a methodology and tools for:

- Analysis of existing Regional capabilities.

• Identification of cross-regional potential synergies.
• Identification of research gaps to actually implement the above potential synergies into practical projects.
• A portfolio of regional financing instruments for the above identified projects.
• A methodology of funding synergies for cross-regional projects, agreed by all the 17 participating Regions, with a Memorandum of Understanding already signed by 11 Regions.
• A methodology to assess the circularity of one project respect another one, validated through a questionnaire filled in by 164 European stakeholders.

The above results was inserted into two practical guidelines: a “Methodology for regional cooperation” and a “Policy Makers recommendation manual” (56).

Despite the wealth of potential funding sources mentioned, it should be noted that public investments for new industrial symbiosis oriented infrastructures, for example through municipalities or provinces, can be important to trigger investments by industrial symbiosis partners.

4.2 Added value through industrial symbiosis and EU-level research and innovation investment

Although 28 EU-funded projects and two industrial symbiosis sites were included in this study, their overall market potential and the value generated are difficult to identify, since absolute numbers are usually not available. Nevertheless, for example, the SHAREBOX project indicates savings of EUR 14 million in cost savings and EUR 54 million in additional sales, demonstrating the potential of industrial symbiosis.

In Domenech et al., a much broader study, a proper market analysis was attempted. The market analysis took two analysis routes. Firstly, by analysing the potential savings that could be achieved by diverting waste from landfill through IS, the study shows that the absolute maximum market potential of IS could reach €72.7b through cost savings due to landfill diversion (e.g. through landfill costs avoidance). Secondly, from the point of view of generation of value, the market potential that could be generated by transactions of secondary materials is estimated at between €6.9b (in the low estimate scenario) and €12.9b (in the high estimate scenario). In both cases, estimations also include conventional recycling solutions, which may fall outside the scope of IS. The estimate of market potential focuses on the residual value of waste. However, due to data limitations it does not account for the upstream market potential of resources not becoming waste, such as “by-products” transactions and reuse/recirculation of materials. Future analysis should try to cover this gap (57).

To put the added value into perspective, we attempted to compare a few quantitative measures.

In 2017, overall CO₂-equivalent emissions in Europe were about 4 480 million tonnes per year. In 2017, greenhouse gas emissions in the EU-28 were down by 22 % compared with 1990 levels, representing an absolute reduction of 1 240 million tonnes of CO₂ equivalents. Out of Europe’s overall CO₂ emissions, industrial processes and product use amount to 8 % or 360 million tonnes of CO₂-equivalent per year (58). The National

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Industrial Symbiosis Programme (NISP) \(^{(33)}\) reported savings of 42 million tonnes of CO\(_2\)-equivalent for the period 2005-2013 with lifetime benefits. In a report by the international consulting group COWI, a very rough estimate extrapolated the potential CO\(_2\)-equivalent savings for all of Europe by extrapolating NISP numbers as 45.5 million tonnes of CO\(_2\)-equivalent, based on an investment initiative of EUR 250 million \(^{(60)}\). Kalundborg reported annual CO\(_2\)-equivalent savings of 275 000 tonnes in 2015 \(^{(61)}\).

These numbers support two findings: (1) the data available is insufficient to make reliable predictions and (2) it seems plausible that universal implementation of industrial symbiosis across Europe could lead to a 10% reduction of CO\(_2\)-equivalent emissions from industrial processes and product use.

In Domenech et al., a single value impact framework was referenced. The total economic value added for 5 years of NISP UK was calculated in a study by Scott Wilson Business Consultancy. The study outlined a range of 53.2 % to 88.6 % for the investment multiplier on the public investment leading to the statement that the ‘triple line benefits achieved to date provide a compelling case for increased investment in the future’\(^{(62)}\).

As industrial symbiosis clearly creates value for industry and the public, **investments in research and innovation are needed on the private and the public side.** In this context, the technologies which are sufficiently mature in terms of TRL should be optimised for industrial symbiosis by bringing their SRL up to deployment stage (SRL=9). This could be easily done by private entities, because the benefits of industrial symbiosis could be easily assessed utilising available tools and techniques, and the main hurdles remain more at the non-technological level (e.g. motivation, trust and organisation). Public entities should only be involved in supporting such projects in cases where significant infrastructure is required and/or significant public involvement in the project is required (e.g. symbiosis involving public utilities and local communities).

On the other hand, for the new technologies needed, which are not sufficiently matured from a technological point of view and have to be developed, stronger public involvement could be envisaged. Following the usual process from fundamental research to application development in industry, both sides need to invest in R&I, and public funding by the European Commission is one important pathway to bridge the ‘valley of death’ between conceptualisation and fundamental research, and concrete implementation in industry, ensuring that the many potential benefits industrial symbiosis can be realised.


5 POLICY RECOMMENDATIONS

5.1 Conclusions

In this chapter, the conclusions highlighted in the body of this report are compiled for easy reference.

- Industrial symbiosis is an important option for establishing a circular economy.

- Of the bigger clusters of projects in the portfolio of the Directorate for Prosperity, the first five of the six established clusters are clearly related to the climate action area of responsibility for DG Research and Innovation, showing significant drive in tackling the global challenge. Industrial symbiosis is the largest cluster (28 projects), indicating that the Directorate for Prosperity has already focused on funding for industrial symbiosis projects. These projects belong to 15 different topics in calls for proposals launched in Horizon 2020. The projects studied fall into two distinct subgroups: process technology projects and projects which develop tools and methodologies for fostering industrial symbiosis.

- In order to assess the status of an industrial symbiosis project adequately, the status of these four dimensions need to be determined separately: (1) technological, (2) business, (3) ecological, and (4) managerial level of maturity.

- The process of maturation of a project is not linear. In many cases, the development will have to restart when the business, technologies, societal framework or regulations change. The SRL will therefore be helpful to realistically assess the current status of an initiative.

- It is considered most effective to focus on established industrial operations that fulfil the preconditions described in Section 3.3 for analysing the opportunities for industrial symbiosis.

- Generally speaking, we observe that the steps involved in fully establishing an industrial symbiosis are often as follows:
  - a simple exchange of heat, material and services (e.g. one partner’s waste is another partner’s raw material);
  - the development of an awareness that a circular economy approach through industrial symbiosis is advantageous with respect to resource optimisation and sustainability;
  - the recognition that a joint business model needs to be developed and established that is fair and equitable.

- Only true win-win situations, where the benefits of the symbiotic cooperation of partners is bigger than the sum of the stand-alone cases, will be sustainable.

- Creating the preconditions, including technologies, willingness to engage in mutual discussions with potential partners, awareness of opportunities, mutual trust and commitment to the concept is therefore a process that will take many years. This should be taken into account by funding bodies, municipalities, industrial symbiosis associations and the potential partners themselves.

- Creating awareness and the willingness of companies to engage in mutual discussions on industrial symbiosis is one route to achieving improved sustainability. This factor is probably the most important one for broader adoption of the concept of industrial symbiosis. Industrial players are often not familiar with the concept, including the potential achievable benefits and how the barriers to cooperation can be overcome.
• The barriers to implementing industrial symbiosis are usually the focus on profitability and competitiveness rather than on cooperation with other industrial companies, a lack of a culture of trust between independent industrial actors, the investments needed, antitrust, legal and IP-protection rules, and unavailability of data on waste streams, including their classification, composition and quantities. The standardisation of the data is an important factor.

• Industrial symbiosis is usually characterised by a supply-driven business model and therefore needs a different marketing approach.

• In our analysis, facilitation is seen as one of the most important elements for fostering the development of industrial symbiosis. It is recommended to involve the industrial park owner/operator, the municipality or the chamber of commerce and/or the association of a cluster of companies as facilitators.

• The most obvious approach is within an existing group of companies in local proximity, be it an industrial park or a more loosely arranged cluster. Local proximity is not a precondition, but almost always makes the establishment of industrial symbiosis more likely.

• We believe that the industrial symbiosis approach can be applied broadly to many different industrial sectors.

• Specific technologies are needed for new industrial symbioses and their development needs to be supported by public and private partners. Benefits from industrial symbiosis mainly fall into the areas of reduction of energy used and avoidance of waste.

• The generation of new jobs, in particular for SMEs, has been identified as one of the benefits of implementing industrial symbiosis.

• To boost investments, investors focusing on sustainable finance and socially responsible investments should be approached, as well as pension funds and the EIB. By investing in the industrial symbiosis approach, a people-friendly industry could be realised and banks, as well as investors in general, should become more aware of the importance of this concept.

• Published figures support two findings: (1) the data available is insufficient to make reliable predictions and (2) it seems plausible that universal implementation of industrial symbiosis across Europe could lead to a 10% reduction of of CO2-equivalent emissions from industrial processes and product use.
5.2 Recommendations

These recommendations are based on the above-listed findings and conclusions. To facilitate adoption, we attempted to focus on the most important ones.

- We recommend further strengthening the support for industrial symbiosis project funding by the European Commission as well as relevant national and regional authorities, based on the benefits for sustainability, competitiveness, regional development and education. As industrial symbiosis clearly creates value for industry and the public, more investments in R&I are needed by both the private and the public sector.

- For this reason, along with funding, instruments and schemes should be developed with the aim of attracting private investment to industrial symbiosis projects. The European Commission should evaluate the possibility of finding suitable ways to link promising R&I projects at appropriate maturity levels to investors and financing to speed up the commercialisation.

- We encourage all potential partners in industrial symbiosis initiatives and facilitators to proactively evaluate all financing options, to overcome the infrastructure investment hurdles and to encourage private investments.

- It is recommended to develop actions to provide a better understanding of industrial symbiosis, including how it can be started, which barriers need to be overcome, how to identify potential opportunities and how facilitation is one of the most important elements needed to secure and accelerate implementation.

- It is recommended to involve the industrial park owner/operator, the municipality or the chamber of commerce and/or the association of a cluster of companies as facilitators.

- It is also recommended to establish a community of practice for industrial symbiosis, which could be an entity with a mandate to provide guidelines for industrial symbiosis (e.g. identify best practices, maintain an up-to-date inventory of industrial symbioses and of opportunities for cross-sectoral cooperation) and promote its benefits and help in educating and establishing industrial symbiosis. This community could publish a handbook on how to establish industrial symbiosis, which would help promote its acceptance and adoption in an accelerated way.

- Establishing trusted, safe and secure data and information exchange platforms will be fundamental since opportunities can only be identified if a reliable and open data source is available for those interested in implementing industrial symbiosis.

- Modern digital tools like digital twins for process modelling and control or blockchain and artificial intelligence for confidential data management should be considered.

- We propose to use the concept of SRL to identify and drive the progress of industrial symbiosis projects and initiatives.

- In Section 3.3 we identified focus areas for R&I investment from the public and/or the private side for methods and tools and technologies. We believe that pilot and testing facilities are critical to demonstrate novel technologies and installations before decision-makers and private investors will have the confidence to make larger investments.

- In this context, it is recommended to use the hubs for circularity, proposed by the SPIRE PPP, as a vehicle to promote industrial symbiosis. This would be a good approach to address the need for a large-scale first-of-a-kind demonstration.
of industrial symbiosis technologies and concepts, paving the way to wider commercial deployment.

- In addition, the potential and the benefits of industrial symbiosis should be included in the education of engineers and business students to ensure the availability of a sufficient skill base.

5.3 Final thoughts

As mentioned at the beginning of this report, there is already a wealth of publications on the topic of industrial symbiosis. Concerning support by the European Commission, a number of directorates-general are focusing on the topic. In the interest of focused and efficient use of the monetary resources of the European Union, it is recommended that the directorates-general involved in industrial symbiosis work closely together. A joint sponsorship of the industrial symbiosis community of practice might be a good starting point. Furthermore, since for example DG Research and Innovation and DG Internal Market, Industry, Entrepreneurship and SMEs are responsible for adjoining parts of the life cycle of industrial symbiosis, we recommend a joint and aligned plan for furthering the importance of industrial symbiosis through public funding from both DGs.

A vision for a well-implemented industrial symbiosis could look like this excerpt from the Kalundborg industrial symbiosis.

![Figure 4. A vision for a well-implemented industrial symbiosis](image)

Finally, we believe that 'a large-scale transition to a carbon neutral industry is not possible without cooperation between industries and a common approach to realize large scale infrastructure' (64).

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(63) Danielsson, S., 'Industrial symbiosis in a circular economy', Energy Crossroads, November 2017  
(http://www.energycrossroads.org/industrial-symbiosis-circular-economy/).

(64) Questionnaire contribution from SDR.
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APPENDIX

The titles and call topics of the projects analysed in this study are as follows.

1. **MefCO2 (SPIRE-02-2014)** – Synthesis of methanol from captured carbon dioxide using surplus electricity.


3. **SYMBIOPTIMA (SPIRE-06-2015)** – Human-mimetic approach to the integrated monitoring, management and optimization of a symbiotic cluster of smart production units.


6. **CoPro (SPIRE-02-2016)** – Improved energy and resource efficiency by better coordination of production in the process industries.

7. **INSPIREWater (SPIRE-01-2016)** – Innovative solutions in the process industry for next generation resource efficient water management.


10. **FALCON (BIOTEC-02-2016)** – Fuel and chemicals from lignin through enzymatic and chemical conversion.


12. **Carbon4PUR (SPIRE-08-2017)** – Turning industrial waste gases (mixed CO/CO₂ streams) into intermediates for polyurethane plastics for rigid foams/building insulation and coatings.

13. **ICO2CHEM (SPIRE-08-2017)** – From industrial CO₂ streams to added value Fischer-Tropsch chemicals.


15. **SCALER (SPIRE-13-2017)** – Scaling European resources with industrial symbiosis.


19. BIOCONCO2 (BIOTEC-05-2017) – BIOtechnological processes based on microbial platforms for the CONversion of CO₂ from ironsteel industry into commodities for chemicals and plastics.


22. RESLAG (Waste-01-2014) – Turning waste from steel industry into a valuable low-cost feedstock for energy intensive industry.

23. FISSAC (Waste-01-2014) – Fostering industrial symbiosis for a sustainable resource intensive industry across the extended construction value chain.

24. RESYNTEX (WASTE-01-2014) – A new circular economy concept: from textile waste towards chemical and textile industries feedstock.

25. ZERO BRINE (CIRC-01-2016-2017) – Redesigning the value and supply chain of water and minerals: a circular economy approach for the recovery of resources from saline impaired effluent (brine) generated by process industries.


28. FReSMe (LCE-25-2016) – From residual steel gasses to methanol.

29. Kalundborg site – The Kalundborg symbiosis is a partnership between nine public and private companies in Kalundborg. Since 1972 they have developed the world’s first industrial symbiosis with a circular approach to production.

30. SDR site – SDR is an initiative taken by 11 energy- and feedstock-intensive companies searching for a reduction in their use of energy and feedstock through industrial symbiosis.
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downloaded and reused for free, for both commercial and non-commercial purposes.
Industrial symbiosis is a cooperative approach between industries: waste, by-products, surplus in energy or wastewater available in one company is supplied to other companies, often in a geographical proximity, for production. It belongs to the policy on circular economy and has significant potential for decarbonising resource-intensive industries. The expert estimates that a general application of industrial symbiosis based on existing technologies has the potential of reducing CO₂ equivalent emissions by 10 %, can save of up to 40 % of fresh water needed by industries and can lead to significant cost savings. The expert recommends the following in his report in particular.

- To establish a community of practice offering guidelines for rolling out industrial symbiosis to more regions and more industries in Europe, which are often not aware how to take this forward.

- To use the concept of symbiosis readiness level to drive industrial symbiosis to full exploitation. This would focus on steps identifying what is needed in terms of technologies, business models, ecology (sustainability) and management in a company.

The potential could be expanded towards industrial-urban symbiosis involving also municipalities and regions interested in cooperating with industries on issues like waste, energy and water (in order to keep such industries in these regions). This could be the foundation for the hubs for circularity, an approach put forward under the Green Deal by DG Research and Innovation and relevant for Horizon Europe.

*Studies and reports*